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Measuring Mass and Speed at the National Training Center

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In this report, a method is proposed and tested for measuring the massing of ground forces in force-on-force simulated combat. The relationship of the mass as well as the speed of an attacking force to attrition-based performance is explored. The researchers used archival data generated at the National Training Center, Fort Irwin, California. Successful attacking task forces were found to have had greater massing and to have closed with the opposing force at higher speed. The methodology developed demonstrates the high potential for using existing data from the National Training Center for theoretical research with practical training implications.

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Measuring Mass and Speed at the National Training Center

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FOREWORD

A major mission of the U.S. Army Research Institute for the Behavioral and Social Sciences is to find ways to improve Army training. How commanders visualize the battlefield has been identified as an important area to understand and integrate into training technology. To study phenomena such as visualization of the battlefield, it is important to use available data opportunities. This report uses existing data from the Combat Training Center data archive to investigate these concerns.

EDGAR M. JOHNSON
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MEASURING MASS AND SPEED AT THE NATIONAL TRAINING CENTER

EXECUTIVE SUMMARY

Requirement:

Field training exercises at the National Training Center (NTC) contribute substantially to training readiness. Measuring performance in this complex training environment is a continuing challenge. A term commanders employ when they visualize the battlefield is Mass. This report represents a proposed methodology for measuring this construct using NTC as a data source.

Procedure:

This exploratory effort undertook to operationally define a measure of mass that could be applied to existing NTC training exercise data. Speed of the attacking task force was also examined. Following a review of previous research efforts, a sample of force-on-force attack battles was chosen in which the attacking unit had either high or low performance. The criterion used for determining performance level was an average of percentage of surviving attacking force and percentage of destroyed defending force.

Findings:

Mass was operationally defined as the concentration of vehicles in the attacking task force around its median-based center of mass. Speed was operationally defined as the speed of movement of the median-based center of the task force. These measures of mass and speed were found to be predictive of the attrition-based measure of performance of the attacking force at the critical time when the attacking force was entering maximum effective weapons range.

Utilization of Findings:

The methodology developed here for the calculation of mass and speed demonstrates the high potential for using existing NTC data for theoretical research with practical implications. Our findings indicate that archival data can be used for the definition and extraction of meaningful military findings that will contribute to an understanding of visualization of the battlefield.

MEASURING MASS AND SPEED AT THE NATIONAL TRAINING CENTER

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MEASURING MASS AND SPEED AT THE NATIONAL TRAINING CENTER

INTRODUCTION

The National Training Center (NTC), with its highly realistic simulated combat environment (Shaddell, 1989), offers unique opportunities for investigating Task Force tactics that might be effective in ground combat. Force-on-force battles in which the rotational unit being trained, the BLUEFOR, carefully plans and carries out a deliberate attack against the resident OPFOR are of particular interest because they are relatively simple from a tactical perspective in comparison to some other types of missions. These deliberate attack missions are also relatively abundant in the NTC data archive (Goehring, 1989b). The relative tactical simplicity as well as the abundance of deliberate attack battles facilitate their use in the search for effective predictors of tactical performance effectiveness.

A commander must visualize the battlefield accurately in order to be successful. How these visualizations, mental representations or images of commanders are formed, modified and utilized are subjects of considerable interest to military trainers, analysts and planners (Kahan, Worley, & Stasz, 1989). Among the paradigms used in this context are the Principles of War and Tenets of Army Operations (Headquarters, Department of the Army, 1993). Included are imperatives to military commanders, such as to synchronize and mass forces at critical locations at critical times on the battlefield while retaining agility and flexibility to exploit any weaknesses of the opponent.

How to operationally define concepts like *synchronization*, *massing* and *agility* using existing data from training exercises carried out at the NTC is a challenge. Hundreds of battles are recorded and preserved in the NTC archive. If methods can be developed to apply these classical concepts of ground warfare to existing data produced by the NTC, much may be learned about what generally contributes to effectiveness of ground combat units. Furthermore, such measures can serve as tools for investigations into the details of how commanders visualize the battlefield. Considerably more work is needed to determine the ways in which commanders form battlefield images.

It would contribute greatly to NTC training exercise analysis to develop validated measures of Task Force performance that can be generated with a

minimum of human effort. Generally such measures as do exist, for example the METT-T index (Root and Zimmerman, 1988), based on attrition measures of both antagonists and a measure of terrain gained or retained, demand both time and scarce resources, especially subject-matter expertise. One solution would be the development of highly or even fully automated calculation of similar descriptive measures. Such measures when they are developed will be inexpensive to apply to a sample of battles or indeed all available battles and will be highly objective. Therefore, the resulting measures will be free of potential distortions of subjective methods, such as hindsight bias (Fischhoff, 1975), where observers are unable to make objective judgments when they know what outcome resulted.

The concepts of *mass* and *agility* are used at the NTC by Observer/Controllers as well as commanders when describing force-on-force attack battles in the NTC environment. Crouch and Morley (1989) discussed these ideas and observed at NTC that a higher degree of concentration and greater agility of maneuver were directly related to success in attacks at the NTC.

Parker (1990), also employing NTC data, unsuccessfully attempted to find a relationship between synchronization and performance of attacking units. Two problems are evident. First, the sample of battles used was very small ($n = 17$) for the detection of effects of a reasonable anticipated magnitude. Second, the definitions used in this research were based on location centroids, which being based on arithmetic averages, are particularly sensitive to extreme values in the vehicle position data. Stafford (1990) was similarly unable to demonstrate substantial relationships between performance of units at the NTC and how they made use of battlefield graphics. Both of these researchers indicated a need for improved data quality or specially collected data from the NTC to validate their research hypotheses. Methodology that can produce valid measurements using the voluminous and imperfect NTC data would contribute greatly to sound tactical analysis.

For this reason we decided to seek in this research effort tactically meaningful operational definitions employing existing NTC data. Mass seemed like a reasonable starting point since it is generally considered to be related to attacking Task Force performance effectiveness.

Dryer (1989) developed a measure of Mass termed Ground Force Concentration that he found to be moderately predictive of the performance

of attacking Task Forces at NTC (Pearson Correlation Coefficient of .64, R^2 = .40, using a sample of 23 BLUEFOR attack missions). The criterion performance measure was attrition-based and is essentially the same as the measure used in the current research (See Methods section).

Dryer geometrically defined the Ground Force Concentration Measure, predictive of this attrition-based performance, as the radius of a circle with its origin at the defensive position center. The magnitude of the radius of the circle, termed **rQ(25),** is such that the circle encompasses the locations of 25 percent of the attacking force players at the Critical Ground Force Attrition Time. Analogous **rQ(50)** and **rQ(75)** calculations were not significantly related to Performance.

He defined the Critical Ground Force Attrition Time as that point during the battle at which 25 percent of the total losses of the combat force within the Critical Ground Force Attrition Area has occurred. The Critical Ground Force Attrition Area is defined as either the intersection of 2000 meter circles drawn with their origins at the maxima of the Relative Attrition Surface Densities for the BLUEFOR and for the OPFOR in the case of "even" battles, or in the case of "OPFOR-dominated" battles, only the 2000 meter circle with origin at the maximum of the BLUEFOR Attrition Surface Density. The Attrition Surface Density was the normal bivariate surface (terrain) density function of player attrition events which was calculated and graphically displayed by modified GRAFSTAT/APL software (See Dryer 1989 for details and computer code listings). We found Dryer's definition complex and confusing.

We intend to be able to develop and validate a related but more parsimonious measure of Ground Force Concentration as a definition of the massing of forces which will be predictive of Task Force performance at NTC. This effort is expected to lead toward the development of automatically calculated measures which are predictive of the attrition-based criterion of Task Force performance.

METHOD

In order to maximize the efficiency of the efforts in developing measures predictive of performance, we focused our attention on NTC attack battles with the highest and lowest performance. Fifty candidate battles were

identified and screened. Many were found to be unusable, due primarily to extensive missing player location data. Following this review 27 battles remained, which included four OPFOR attacks of defending BLUEFOR. Very few low-performing OPFOR attacks battles exist in the archive. OPFOR attacks were included only to determine if they were radically different from the BLUEFOR exercises. This sample was judged sufficient for the scope and objectives of this investigation.

Performance Criterion.

The attrition-based criterion of performance used was based on a combination of the destruction of the Combat Power of the defending force and the survival of the attacking force Combat Power. Only tanks and tank-killing systems were included for this purpose. Dryer (1989) included most of the tank killing systems but did not include the OPFOR AT-5 (Sagger) system. The Combat Force, number of tank and tank-killer weapon systems, at the start of the battle was used as a basis for calculating the percentage of combat force loss during the exercise independently for the attacking and defending forces. The performance criterion was then defined as the arithmetic mean of the percentage of attacking force survival (100 minus the percentage of combat force loss) and the percentage of defending force losses.

This attrition-based definition of performance was employed rather than Casuality Exchange Ratio (CXR) (proportion of destroyed enemy force divided by proportion of destroyed friendly force) for several reasons. First, it is the identical definintion used by Dryer (1989). Second, it has a defined range between zero and one. The CXR gives, in our opinion undue weight to survival of the force in the denominator of the statistic, typically the friendly force. In addition, as the proportion in the denominator approaches zero the maximum value of the statistic is unbounded.

Replication Objective.

We began this research effort with the goal of replicating the relationship identified by Dryer (1989) between ground maneuver concentration and attrition-based performance in units executing attack battles at the NTC. Our intention was to first replicate the finding using an independent sample of battles and then to proceed with methodological development of the automated calculation of the measure.

First, a variant method for calculating the rQ(25) Ground Force Concentration measure developed by Dryer was defined, because the modified mainframe software was not accessible within the time horizon of this project. But we were able to develop a very comparable definition. Calculation of the Ground Force Concentration Measure according to Dryer's method requires a Center of the Defending Force and identification of the Critical Ground Force Time.

Defending Force Center.

Two raters independently replayed the battles in the sample using the General-purpose NTC Analysis of Training Tool (GNATT, See Goehring, 1989a) and developed individual criteria based on reading Dryer's definition. Grid coordinates of the location that was judged by visual inspection to be the Center of the Defensive Force were recorded. To avoid hindsight bias this was accomplished without knowledge of whether the performance of the unit conducting the attack battle was categorized as successful or not.

In the instrumented data numerous defender vehicles appear tens of kilometers from the general area in which the battle occurs. On the one hand, both raters excluded such far distant vehicles in determining the centers of the defending force. On the other hand, vehicles which were directly engaged in the fighting or were in close proximity to it were included. However, a discrepancy in the judgments occurred in the case where players were in close proximity to the defending minefields and the battle as it unfolded, but who were beyond direct-fire weapons range and did not actually participate in the battle. For example, suppose the defensive line runs many kilometers North to South and the attackers chose to only attack the most Northerly segment of the defensive line. The defenders to the South did not engage their weapons or move their vehicles at all during the course of the battle. So, on the one hand these players were prepared to be involved in the battle and indeed would have been had the attacker selected a more Southerly advance, but in fact were not actually involved in the battle and could as well have not been there, as things turned out. The rater judgments differed depending whether these players were counted in the determination of the Center of the Defensive Force. Dryer's discussion gives no indication of how he resolved such problems in determining Centers of Defensive Forces in his sample of NTC battles.

The mean difference in judgments across battles between the grid locations we identified as the Center of Defensive Force was 1.5 km. The minimum difference was 0 km and the maximum was 5.8 km and the modal discrepancy was 1 km. Because of the extreme numerical range in raw grid coordinate values the correlation coefficient calculated as a measure of interrater reliability was spuriously high. Likewise the Spearman rank order was extreme (rho=.98). Nonetheless, the extent of agreement between sets of ratings was judged acceptable. These two sets of data were judged not to differ appreciably. The two sets of data were averaged.

Critical Ground Force Attrition Time.

The Critical Ground Force Attrition Time is defined here as that time in the battle when 25 percent of the attacking force losses had occurred. Each battle was viewed using the GNATT system to exclude extraneous player losses prior to the movement of the attackers toward the defenders. Following Dryer, when 25 percent of the attacking force losses had occurred, that time was recorded as the Critical Ground Force Attrition Time.

Specially-developed software calculated the value for the **rQ(25)** measure of Ground Force Concentration based on the instrumented NTC player location data using the Critical Ground Force Time and the Center of Defensive Force parameters from each rater.

RESULTS

The rQ(25) measure of Ground Performance Concentration was then related to performance of each attacking unit (Figure 1). Both inspection of the Figure 1 and the correlation coefficient based on these data indicate an absence of a relationship between the variables. Thus, using a slight variation of Dryer's method and a comparable sized sample we are not able to replicate his finding that Ground Force Concentration is related to performance effectiveness of attacking units.

We next decided to explore alternative approaches. Rather than calculate a measure of mass or Ground Force Concentration with respect to the location

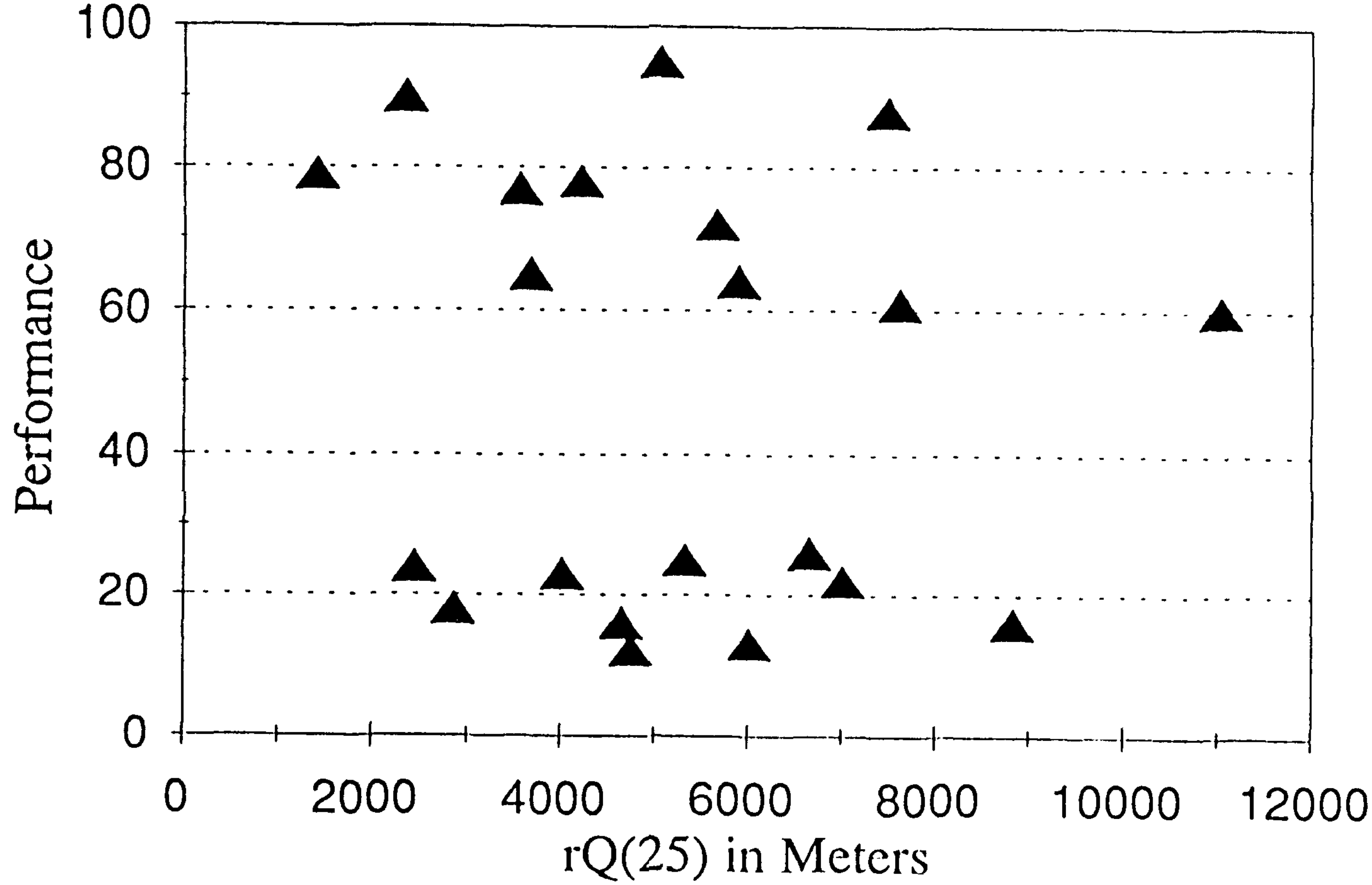

Figure 1. Relationship between Dryer's Dispersion and attacking task force performance.

of the defending force, we conceptualized the attacking force as continuously being massed or dispersed to a greater of lessor extent. The general idea of the measure of dispersion based on the median calculation seemed sound, solving certain position-location loss problems as well as critical determinations of precisely which players are active participants in the battle. We, therefore, defined a new measure of Ground Force Concentration—**Dynamic rQ(25)**.

Dynamic Concentration.

First, the Median Task Force Location in the attacking force was calculated at five-minute intervals throughout the battle by finding the median Easting location and the median Northing location of all attacking force tank and tank-killer vehicles. The concentration of these vehicles of the attacking force is then defined, based upon their dispersion with respect to the Median Task Force Location, as the magnitude of the radius of a circle which includes 25 percent of these players at each point in time during the battle. This measure of Ground Force Concentration, which theoretically exists at every point during the battle, is termed the **Dynamic rQ(25)**.

Each battle in the sample was examined without regard to whether it had a high or low performance to determine when the main element of the attacking force approached to within 3 km of the forward edge of the defending forces. The Critical Minimal Dispersion Point was defined as the minimum dispersion value, measured by **Dynamic rQ(25)**, occurring within thirty minutes following the main element of the attacking force approaching within 3 km of the forward edge of the defending forces.

Figure 2 shows that the **Dynamic rQ(25)** measure of Ground Force Concentration at the Critical Minimal Dispersion Point is predictive of the attrition-based performance measure for the BLUEFOR attack battles ($r = -.38$, $p = .04$, $n = 23$). Although the measure of Ground Force Concentration is a positively skewed variable, there is, arguably, an outlier datum. When the data for that training exercise is eliminated the correlation decrease slightly ($r = -.37$, $p < .05$, $n=22$). For OPFOR attacking units ($n = 4$) the relationship appeared generally consistent but was not statistically significant, and is therefore inconclusive. Although our definition of Ground Force Concentration is somewhat different from that of Dryer, the obtained Pearson Correlation Coefficient does not differ significantly ($Z = 1.16$, $p > .1$).

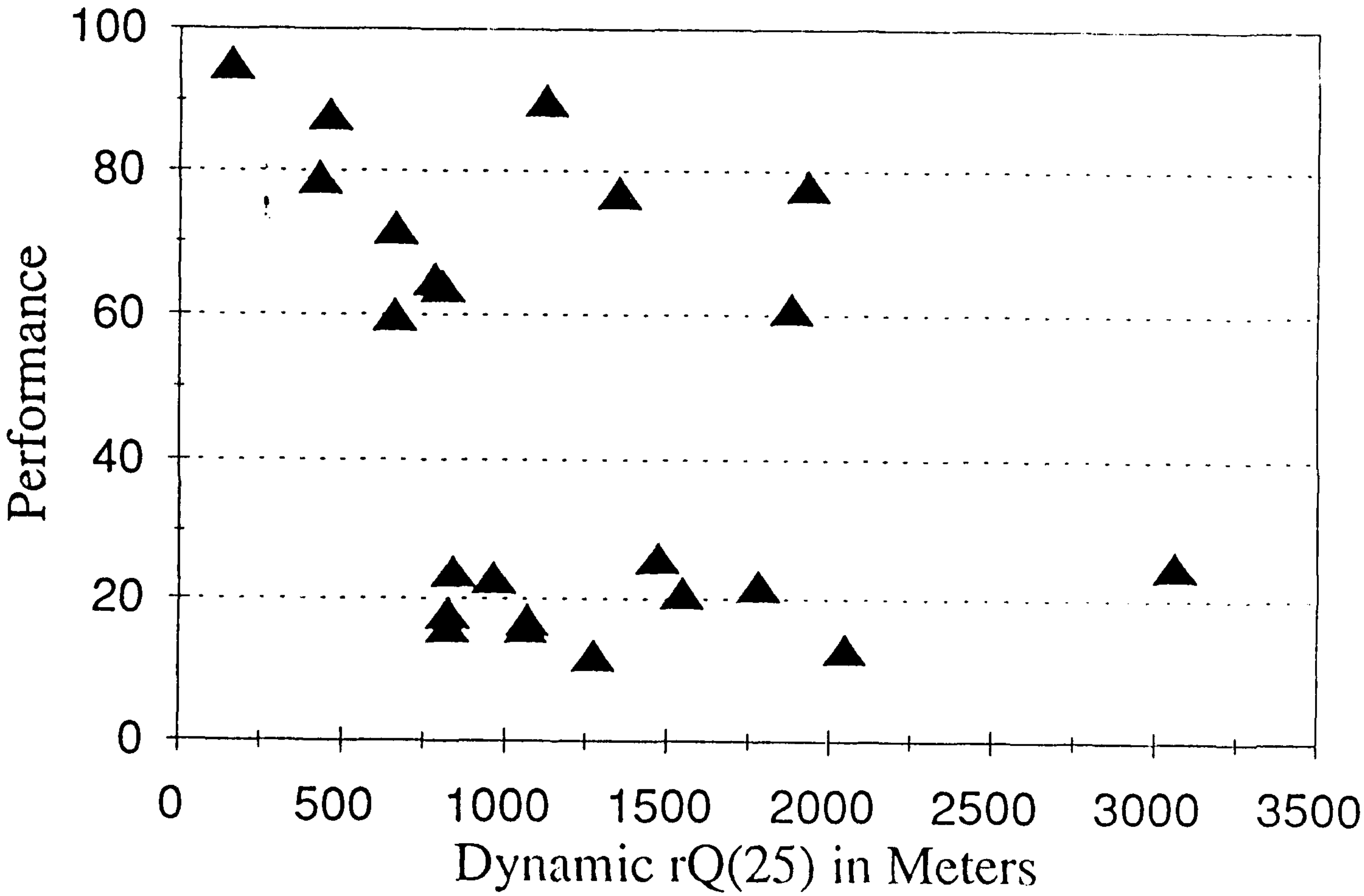

Figure 2. Relationship between Dynamic Dispersion and attacking task force performance.

Therefore, although our method differs somewhat and we did not strictly speaking replicate the findings of Dryer (1989) this finding is consistent with the earlier work in general terms, showing that measurable Ground Force Concentration of an attacking task force does predict performance effectivenessat NTC.

Figure 3 and Figure 4 show **Dynamic rQ(25)** time profiles for a high-performing task and a low-performing task force. First, the overall magnitude of **Dynamic rQ(25)** is much smaller for the high-performing unit as the relationship in Figure 2 would suggest. Secondly, over time the high-performing unit demonstrates increasing concentration and therefore, presumably, an increase in massing, while the low-performing unit shows the reverse. The comparison point between the battles is shown by a vertically aligned arrow in each figure where the unit was judged 3 km distant from the defending force. Figure 5 shows a battlefield view generated by GNATT2 of the same high-performing task force as Figure 3 at the Critical Minimal Dispersion Point. Approximately six square km are displayed. Figure 6 shows a comparable battlefield view for the same low-performing task force as Figure 4 at the Critical Minimal Dispersion Point (that is, the minimum **Dynamic rQ(25)** value occurring within thirty minutes following the main element of of the attacking force approaching within 3 km of the forward edge of the defending force). Approximately 120 square km of terrain are shown, the task force is approximately 11 km in length at this point in the battle. In both figures only the attacking BLUEFOR players are shown and the arrow in each figure indicates the approximate direction of advance. The rectangular figures are defending force minefields. These two battles show a striking contrast in dispersion of forces or massing at a very critical point in the battle.

Speed of Movement.

One tactical characteristic of an attacking task force is its speed of movement. For an attacking task force speed of movement can be defined in terms of movement of the median location of the task force. A reasonable hypothesis is that a task force which can effectively mass its forces is also likely to employ greater speed of movement when engaging the enemy. As these data could be easily obtained from the sample and because of the largely

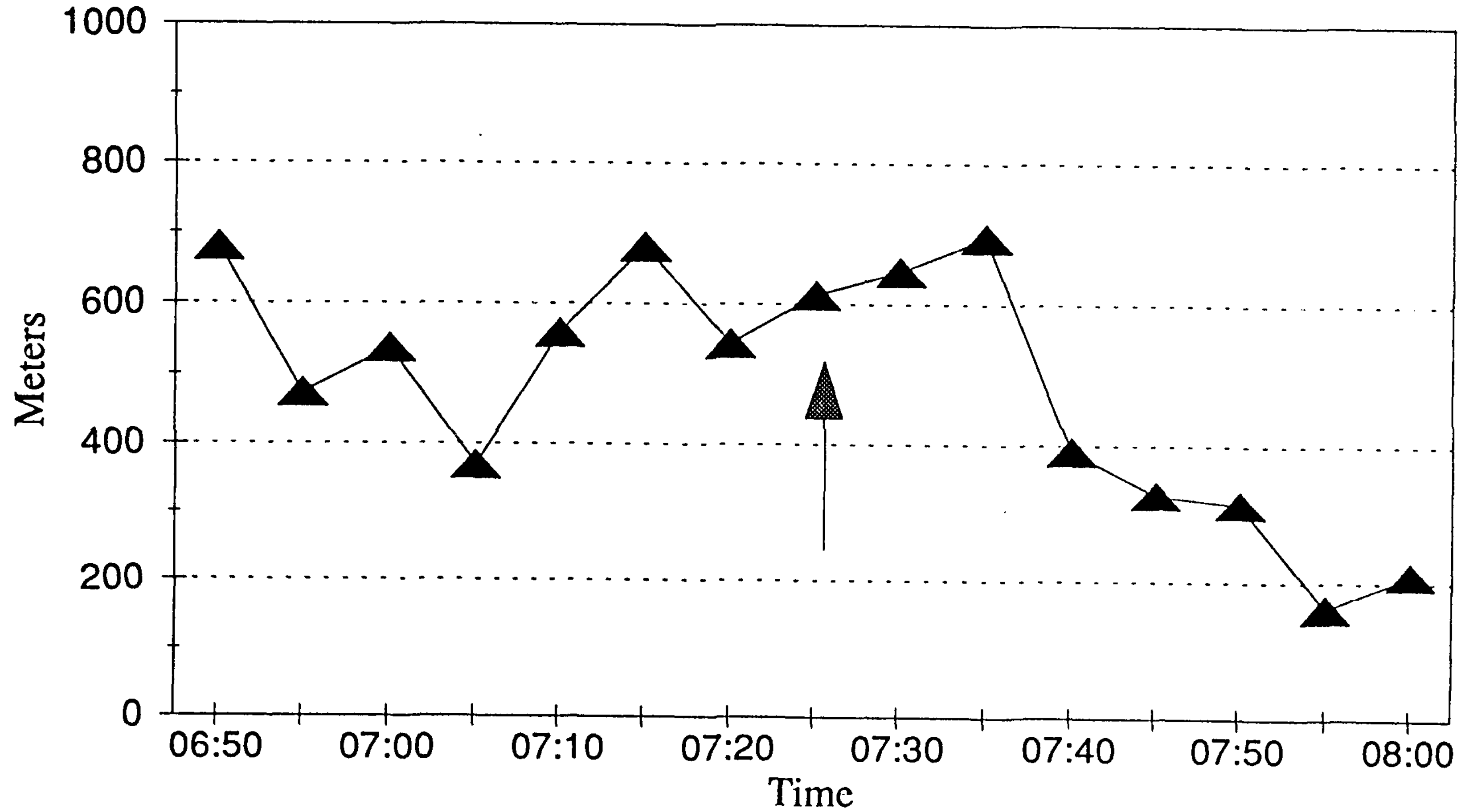

Figure 3. Dynamic Dispersion of a high-performing task force.

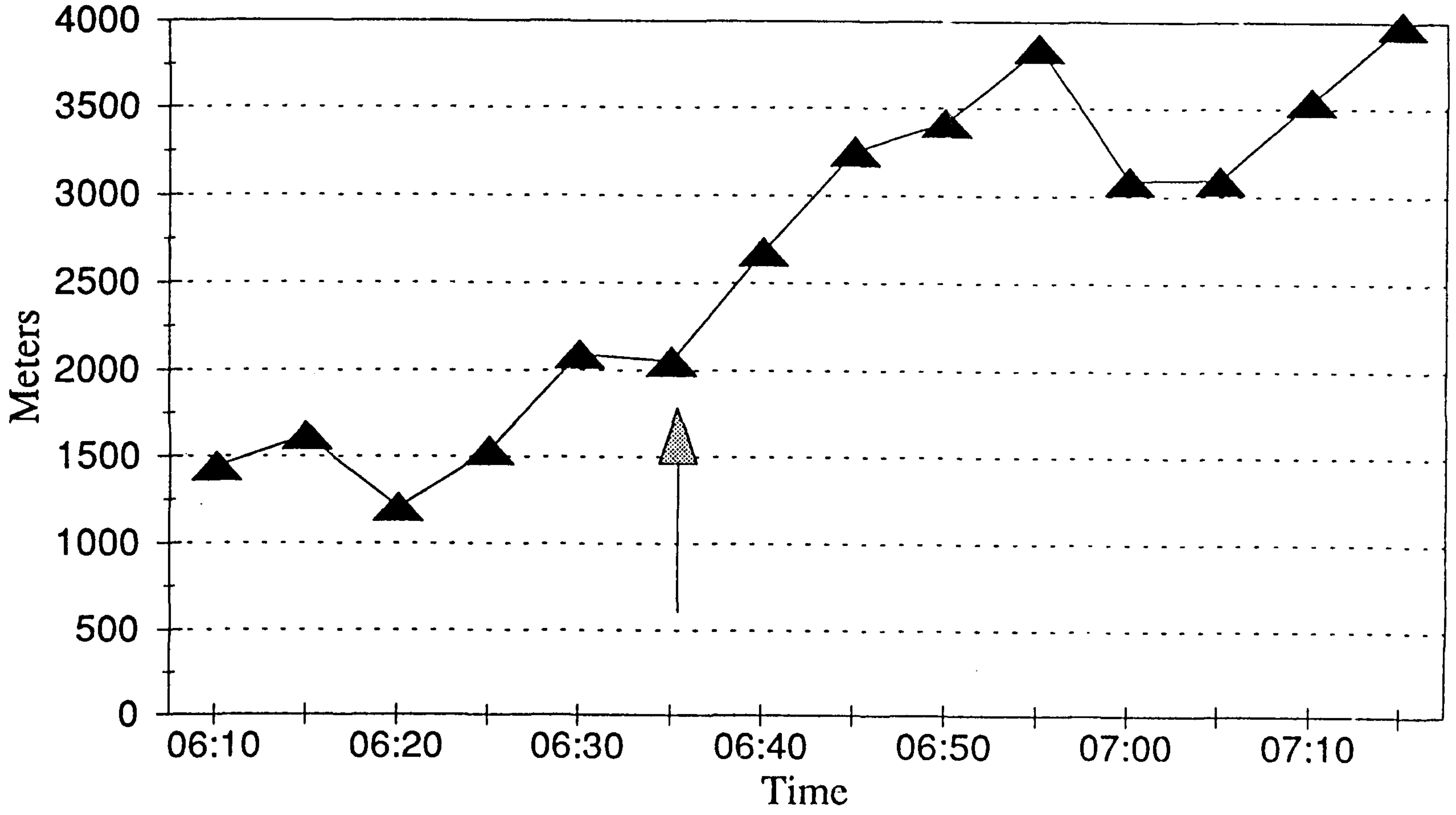

Figure 4. Dynamic Dispersion of a low-performing task force.

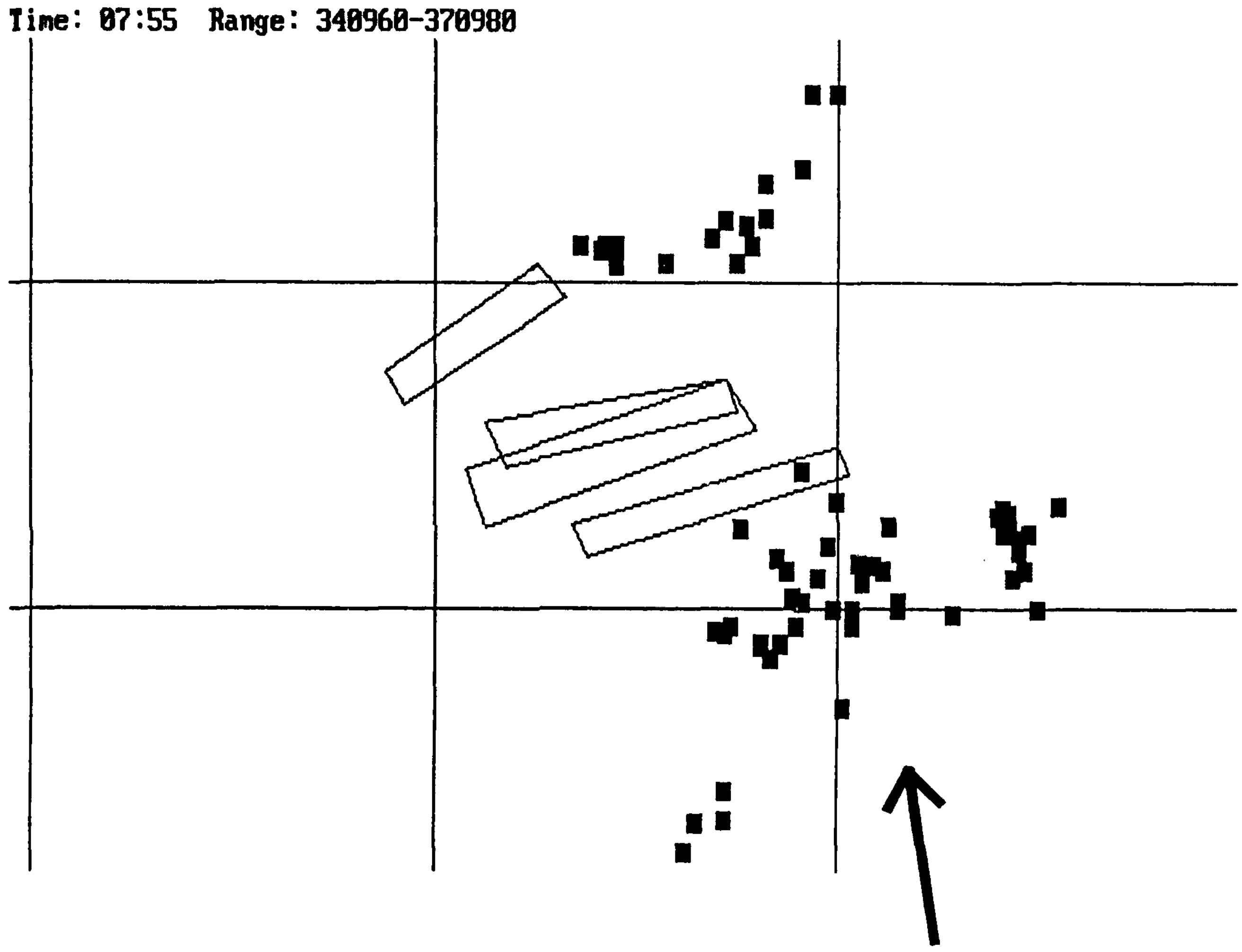

Figure 5. Battlefield view of vehicles in task force with low Dynamic Dispersion.

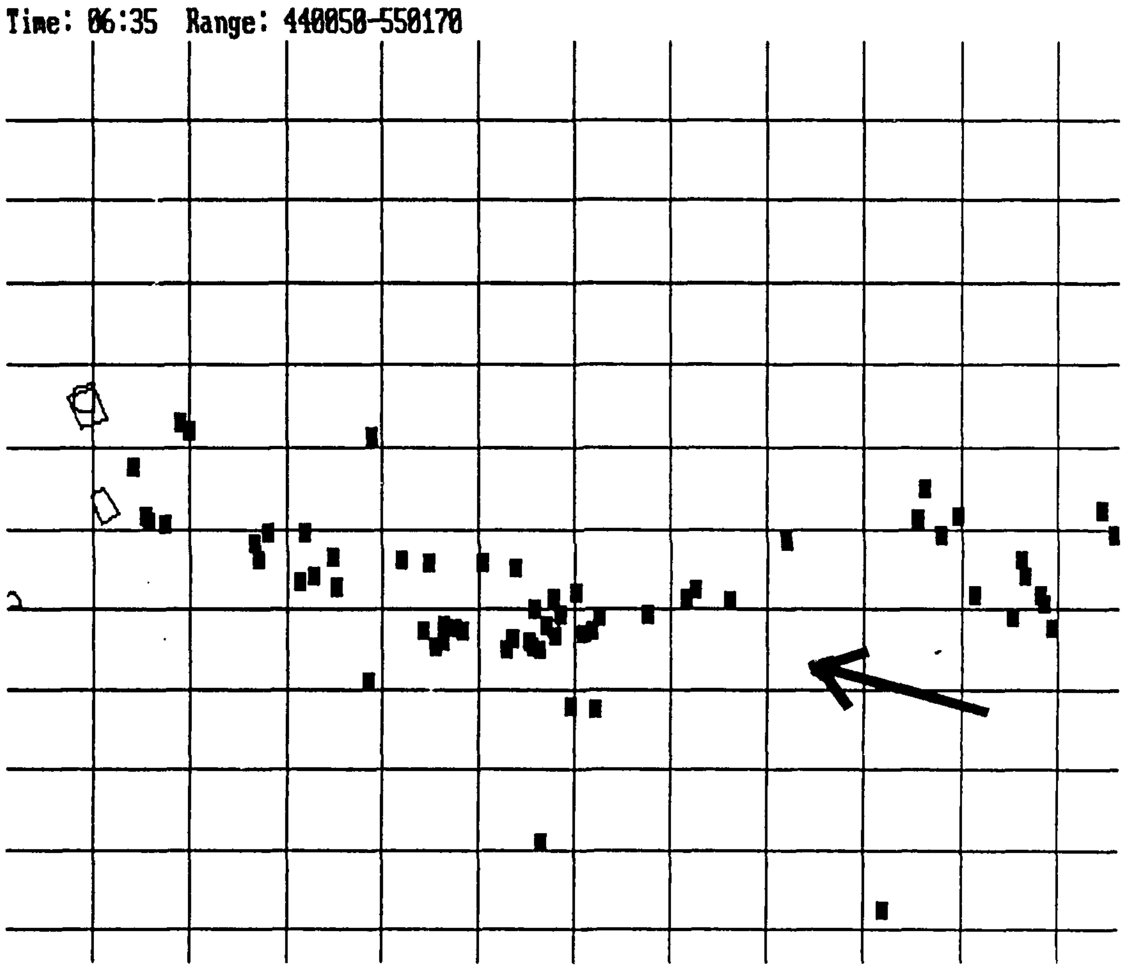

Figure 6. Battlefield view of vehicles in task force with high Dynamic Dispersion.

exploratory nature of this investigation the speed of the attacking task force was explored.

We calculated speed of movement profiles for all of the battles in the sample. Speeds of movement of different task forces at different times vary widely, from zero to nearly 60 km/h. Since one critical time had already been carefully identified in the attack battles in the sample, the speed of movement of the task force when it was 3 km from the defensive force was recorded as the attacking unit speed.

Correlations were calculated between BLUEFOR attacking task force speed and attrition-based performance ($r = .35$, $p = .05$, $n = 23$), and between BLUEFOR attacking task force speed and the **Dynamic rQ(25)** at the Critical Minimum Dispersion Point ($r = -.37$, $p = .04$, $n = 23$). Figure 7 shows speed profiles for a high and a low performing task force. Both profiles begin when the unit is 3 km from the forward edge of the defending force. The speed of the low performing unit decreases to zero, while the high performing unit is able to maintain its speed. Speed of movement was also calculated for the limited sample of OPFOR attacks. The findings were not notably different from those of the BLUEFOR Task Forces.

When both Speed of Movement and Ground Force Concentration for BLUEFOR Task Forces are regressed on Task Force performance the additional predictability added by the speed variable is small ($R = .44$, $F = 2.44$. $p = .11$, two-tailed statistical test) and the statistical significance is marginal. The two variables are themselves correlated and appear to be predicting nearly identical components of variance in performance, and thus in combination are not much better at predicting performance effectiveness.

DISCUSSION

We were successful in developing a simplified methodology for measuring Mass and speed as defined by Ground Force Concentration and Speed of Movement, respectively. Both of these measures taken when the attacking force approaches to maximum weapons range were predictive of the attrition-based performance of BLUEFOR Task Forces. Although we were unable to replicate Dryer, our measure of Mass, which differed in detail but not in substance from his, produced results which were generally consistent with his

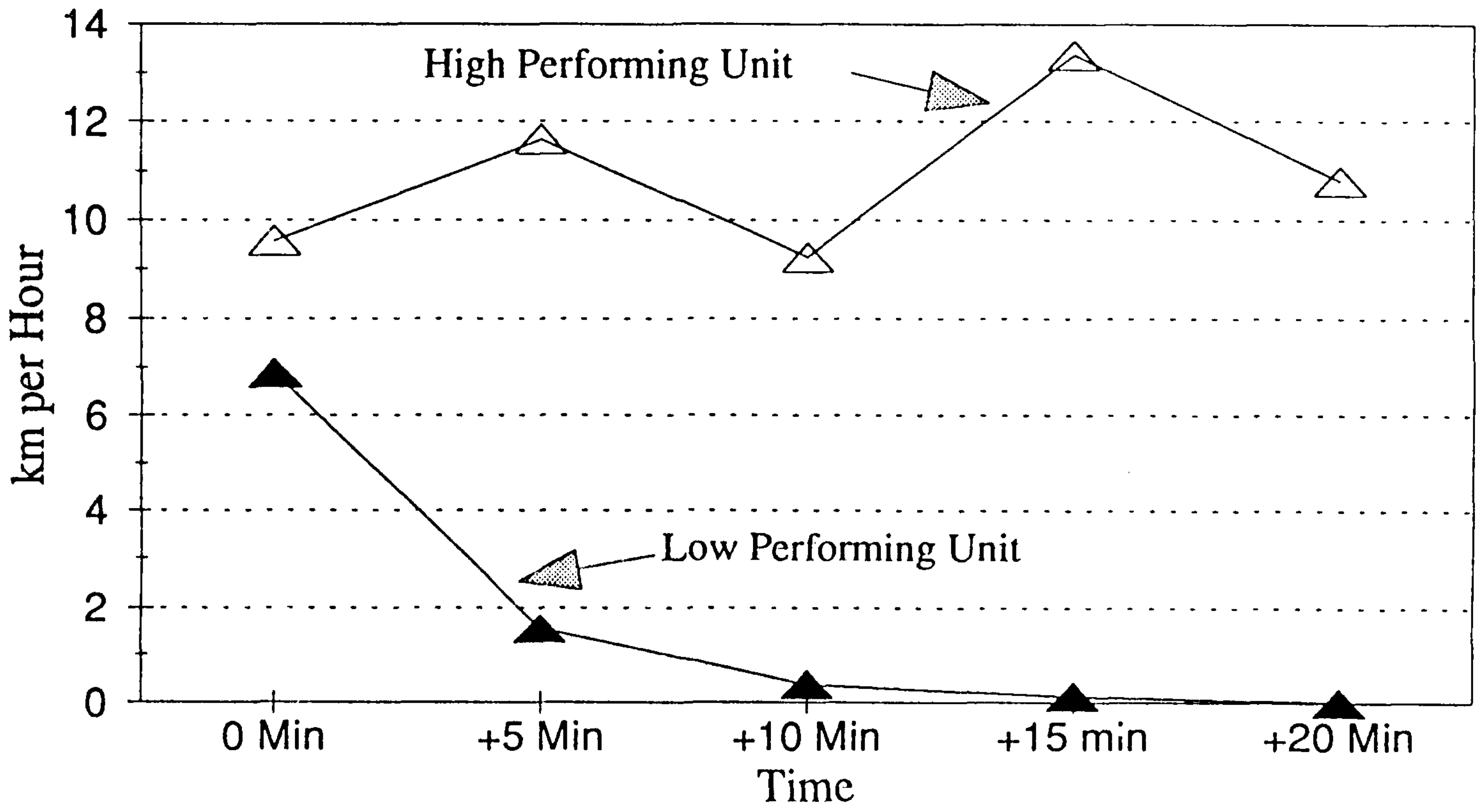

Figure 7. Speed of Movement profiles for high- and low-performing task forces.

findings. We believe our method is more easily replicable and that it will be easier to automate.

In order to proceed to generate these measures by automatic means it will be necessary to develop a completely objective measure of the Critical Minimal Dispersion Point. Because of the robustness of the Median Task Force Location as a measure of position of a moving unit, it may serve as the foundation of a definition for establishing the Critical Minimal Dispersion Point.

The methods developed here may be usefully applied to the SIMNET environment (Pope and Schaffer, 1991). The data are similar in form and substance and the measures of mass and speed might provide additional dimensions for training feedback. For this purpose, analogous measures of mass and speed at company and platoon levels might prove valuable.

The best estimate of the amount of variance in performance which is predictable from the combination of mass and speed, as measured, is about 20 percent based on this sample of training exercises. This is both good news and bad news. First the good news. Using archival records, some recording training events which occurred as long ago as seven years, there is sufficient predictability to warrant continued effort along these lines. The bad news is that 80 percent of the variance is accounted for by a variety of other factors. What are some of these factors? There are a number of promising candidates including the amount of training of the task force, but more work is needed concerning the measurability and interrelationships among these concepts.

CONCLUSION

NTC archive data is an invaluable and convenient source for information needed to derive measures that are predictive of the performance of ground task forces. We focused here on BLUEFOR Deliberate Attack battles but there is promise that these methods can be expanded to a broader range of battles. For example, movement to contact battles typically result in contact between forces and may be amenable to similar methodology.

Mass and speed of an attacking task forces are predictive of their performance effectiveness. Therefore, it is of no surprise that these constructs are among those employed by commanders as they plan and

conduct their battles. The importance of this research effort is that we have demonstrated the validity of these ideas.

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